FOLIAR FEEDING OF ESSENTIAL NUTRIENTS TO PLANTS

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FOLIAR FEEDING OF ESSENTIAL NUTRIENTS TO PLANTS

By James W. Schwartz 1/

Recent energy shortages have focused attention on the possibility of supplying part or all of the plant nutrients to aboveground plant parts. Environmentalists believe that foliar feeding can reduce leaching, runoff, and general inefficiency of soil-applied fertilizers. The practicality of foliar feeding based on today's utilization of water-soluble fertilizers and routinely used pesticides is discussed in this report. Although the trunk, stems, buds, flowers, and fruit absorb nutrients, the foliage generally constitutes the largest absorptive surface and justifies the term foliar feeding.

Reports of substances applied to the trunk and limbs of trees began appearing over 150 years ago (7, 9, 13). 2/ Development of radioisotopes in the mid-20th century furnished much needed tools for more in depth studies of the absorption process. Some excellent reviews and discussions of foliar feeding have appeared in recent years (3, 11, 19, 26, 27).

NUTRIENT ABSORPTION AND TRANSPORT

Several theories have been proposed to describe the mechanisms of foliar absorption. The problem is to determine how nutrients are absorbed by a leaf that is covered with a layer of cuticle generally considered impervious to liquids. Some investigators attribute absorption mainly to passage of substances through the stomatal pores (2, 8, 28). Structures called ectodesmata were identified as pathways for absorption by other researchers (10, 12). More recently absorption has been described as taking place through pores, holes, or channels in the cuticle, with some researchers suggesting that the pores or holes are electrically charged, accounting for the selective absorption of compounds (5, 16, 21).

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2/ Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Agreement has not been reached on whether foliar absorption is a passive or active process. Whatever the process of absorption, the nutrients to be utilized must be transported to other plant parts. The rates of absorption and transport are different for each element and for each crop species. When applied in foliar sprays to 'Blue Lake' bean plants, urea nitrogen, potassium, phosphorus, and sulfur were considered mobile, zinc copper, manganese, iron, molybdenum, and boron intermediate, and calcium and magnesium immobile (4). Environmental conditions such as temperature and humidity also affect the rates of absorption and transport.

MACRONUTRIENTS

Plants require 17 nutrient elements, 14 of which are normally obtained from the soil. The elements are broken down into macronutrients and micronutrients depending on the amount required for growth. The six macronutrients and the amounts (p/m) in plant tissue are as follows:

	Thousands
Nitrogen	10-60
Phosphorus	2-8
Potassium	10-30
Calcium	1-30
Magnesium	1-10
Sulfur	1-3

Nitrogen

Urea is generally used as the nitrogen source because it is water soluble
ed by most crops. In addition, urea increases the
of other elements when they are combined with it.
required by plants, repeated applica-
void injuring the foliage.
gnesium sulfate, with nitrogen
gen in or on the leaf. These
rated solutions to be used.

barley, potatoes, jute, corn,
ield advantage over
ffee, cacao, and banana trees
rate of nitrogen for foliar
3.0 percent solution. For
necessary for normal growth

and development. Foliar sprays have been most useful in correcting deficiencies of fruit trees during periods of stress, such as drought, pruning, or disease.

Phosphorus

Applying phosphorus in a foliar spray to plants avoids fixation of phosphorus in the soil in unavailable forms. Foliar feeding of phosphorus to such crops as corn, tomatoes, and beans generally increases its efficiency up to 20 times greater than in soil applications, but repeated sprays are necessary to maintain growth. For many crops the optimum temperature for uptake is 21° to 30° C, with higher or lower temperatures inhibiting uptake.

Up to five supplemental sprayings of phosphorus applied to sugarcane failed to increase yield or quality of sugar content. Foliar sprays of phosphorus can be used to correct its deficiency in fruit trees during stress periods but cannot supply all the phosphorus needs of a tree. Foliar sprays of nitrogen, phosphorus, and potassium at 1.5 percent solution increased photosynthesis in sugar beets by 30 to 60 percent for 1 to 2 weeks after treatment (6).

Potassium

Foliar applications of potassium to beans and tomatoes are utilized most effectively at 25° to 30° C. Beans retain more nutrient spray and absorb it faster than the tomato plant (24). Foliar sprays of potassium can be applied to dormant fruit trees but generally are useful only in critical situations. With most tree crops the total amount of potassium applied to foliage is considered minor compared with required amounts derived from the soil. Potassium applied to leaves of some vegetable crops increased dry weight when low or medium rates of soil-applied potassium were used. Generally a 0.5 to 1.0 percent solution of potassium sulfate is effective and three to five sprayings during the growing season are necessary.

Calcium and Magnesium

Compared with the other macronutrient
in foliar sprays are considered rather imm
of these two elements have been use
For example, blackheart of celery
of calcium chloride to the foliage
tomatoes can be controlled with ca
of development. Foliar sprays of
to control magnesium deficiency in
required to control the same sympt
deficiency of celery can be contro
magnesium sulfate per acre at week
tons of hydrated magnesium sulfate

Apple trees deficient in magn
applications of dolomitic limeston

to 3 years to be effective. Temporary control of the deficiency can be effected by foliar sprays of magnesium sulfate.

Sulfur

Sulfur compares with phosphorus in mobility in the bean plant. Foliar sprays of sulfur can be used as a supplement to soil- and atmosphere-derived sources. Sulfur is very mobile when first applied, but it is rapidly inactivated by metabolically active young leaves. Sulfur dust applied to the leaves of lemon trees was absorbed and utilized, increasing the quality of the fruit (25). Sulfur deficiencies become more widespread as high-analysis fertilizers are used that do not have sulfur as a contaminant.

MICRONUTRIENTS

Six micronutrients are normally considered for supplemental fertilization. Because they are required in small amounts, foliar feeding is more applicable with them than with macronutrients.

The six micronutrients and the amounts (p/m) in plant tissue are as follows:

Iron	30-300
Zinc	10-100
Copper	5-50
Manganese	20-300
Boron	10-100
Molybdenum	1-5

Iron

The iron availability in the soil is pH dependent. For each unit increase in pH, the solubility of ferric iron decreases one-thousandfold and that of ferrous iron decreases one-hundredfold (20).

Iron was the first micronutrient scientifically utilized in foliar sprays. It is only slightly mobile in most plants; however, many plant species have been successfully treated with foliar sprays for chlorosis caused by iron deficiency. For example, sorghum grown in alkaline soils is highly susceptible to chlorosis, and soil treatments are not economically practical. Some success has been attained by treating chlorotic sorghum with foliar sprays of iron. Spraying severely chlorotic sorghum plants one to three times with a 3 or 4 percent ferrous sulfate solution corrects

the deficiency and increases yields in some instances. A wetting agent with the foliar sprays is essential, along with early spraying of plants.

Leaves of cotton, beans, and sorghum treated with iron^{59} and then autoradiographed showed that iron is reasonably mobile, being transported by the phloem and xylem to young growing tissue. Iron deficiency chlorosis of soybeans can be corrected by foliar sprays of iron at 0.1 pound of iron per acre with a wetting agent to assure even coverage. The best time for spraying is as early as possible after chlorosis is apparent. Soybean varieties differ in susceptibility to chlorosis and resistant varieties should be selected. Corn transports foliar applied iron very slowly; however, growth regulators can increase the mobility of the absorbed iron. Isolated cells of tobacco absorb iron best at 25° C; young leaf cells absorb iron most effectively.

The first large-scale users of foliar feeding were pineapple growers in the Hawaiian Islands. The pineapple crop is routinely sprayed with ferrous sulfate to alleviate iron deficiency.

Zinc

Soil zinc is pH dependent with a hundredfold decrease in solubility for each unit increase in pH (20). Consequently, liming acid soil can produce deficiencies requiring zinc fertilization. Also, organic soils and eroded or leveled soils are frequently deficient. Soil applications of zinc may need to be repeated every 5 years, as many soils fix the zinc in unavailable forms.

Since zinc is more mobile in the plant than iron, foliar sprays are longer lasting, requiring fewer applications. A wide variety of plant species has been successfully treated with zinc sprays.

Frenching or mottle-leaf of citrus trees is attributed to zinc deficiency and is easily corrected with foliar sprays of zinc. Grapefruit trees and orchards in Oregon have also been successfully treated for zinc deficiency with foliar sprays of 0.5 to 1 percent zinc concentration.

For field beans, one or two sprays of zinc sulfate at 1 pound of zinc per acre is effective. For best results, the zinc should be applied as soon as possible after deficiency symptoms are seen. One to three foliar applications of 0.3 to 1 percent zinc sulfate solution to corn will correct zinc deficiency and may increase yields depending on the severity of the zinc deficiency. Zinc deficiency symptoms of tomatoes can be corrected by adding zinc sulfate to the transplant water. To correct deficiencies later in the season, zinc sulfate sprays are sometimes used.

Zinc-deficient wheat can be treated with foliar or soil applications of zinc sulfate. Foliar sprays of zinc sulfate at 0.3 to 1 percent concentration at tillering stage are effective, requiring 5 to 20 percent of the amount applied to the soil.

Copper

Copper is pH dependent in the soil and is about the same as zinc; however, copper deficiencies are not as common as zinc deficiencies. Many of the sprays used to control diseases contain copper. Where pesticide sprays are routinely used, copper toxicity can become a problem. However, in citrus plantations, copper deficiency leads to a condition called dieback, which can be corrected with copper sprays. Young apple trees with symptoms of dieback or withertip can be treated with a Bordeaux mixture of 4 pounds of copper oxychloride per 100 gallons of water. A copper sulfate solution of 1 to 10 pounds of sulfur per acre corrects copper deficiency in wheat when applied in a foliar spray. A direct spray on the plants at critical stages of plant growth is recommended, particularly at flowering.

Manganese

Manganese deficiencies usually occur on high pH soils that are well drained or soils with high organic matter. Correcting manganese deficiencies by lowering soil pH is difficult, as is adding manganese compounds to the soil. Foliar sprays of manganese sulfate are often very successful. Manganese deficiency of soybeans can be controlled by foliar spraying with 1 to 5 pounds of manganese per acre. One to three sprayings may be necessary and the varieties may differ widely in response to the spray. Soybean plants that contain less than 20 p/m of manganese will probably respond to foliar applications of manganese. Oats can be treated for manganese deficiency with 2 pounds of manganese as manganese sulfate in 15 gallons of water per acre at critical stages of growth. Plants containing less than 25 p/m of manganese at the boot stage will probably respond to supplemental manganese.

Repeated sprays of manganese sulfate are necessary for continued correction of manganese deficiency of cereals, beets, and peas. Spraying wheat, oats, and beets as soon as deficiency symptoms are apparent will give best results. For peas, two sprayings at time of flowering will help control marsh spot. Sprays of 1 pound of manganese per 100 gallons of water are effective for manganese deficiency of orange trees, sometimes increasing yields of oranges over 20 percent.

Boron

Because drought decreases the availability of boron in soils, foliar sprays are sometimes useful. Also, boron can be combined with other spray materials and save time and money. However, several sprayings are necessary as the mobility of boron in the plant is considered intermediate to immobile.

Experiments with cotton in which foliar sprays are compared with soil fertilization showed that no one method was consistently better and suggested that the boron application be combined with other materials (18). Boron deficiency in pears resulting in twig dieback and blossom blast can be controlled with a fall application of foliar spray at 1 pound per acre of boron. Controlling boron deficiency in orchards of the Eastern United States

has been demonstrated by utilizing foliar sprays. Success has been reported with 4 pounds per acre of sodium pentaborate applied 1 to 3 weeks after petal fall.

Studies on tomatoes and cantaloups showed that foliar sprays of magnesium sulfate at 4 pounds per acre and borax at 2 pounds per acre were beneficial. The authors (23) recommended two foliar sprays for cantaloups, the first one when the vines begin to run and the second when the crown fruit is 1 to 2 inches in diameter. For tomatoes, the first spray should be applied when the crown fruit begins to turn and the second at the third week of harvest. They reported an economic return of $37.44 per acre based on foliar feeding.

Molybdenum

Molybdenum deficiency of crops is worldwide and is especially common in legumes. Since molybdenum is less available in acid soils, applying lime will increase the supply of molybdenum. Foliar sprays are effective for correcting this deficiency even though molybdenum is only slightly mobile in plants. The very small amount needed by plants probably accounts for the effectiveness of sprays. Since excess molybdenum is highly toxic to livestock, care must be exercised not to overapply this element.

Citrus trees in Florida responded to foliar sprays of sodium molybdate or ammonium molybdate at 0.1 ounce per 10 gallons of water per tree. Canning peas, sweet corn, and red clover showing molybdenum deficiency symptoms have been successfully treated with a foliar spray of 2 ounces of sodium molybdate per acre (15). Experiments with soybeans on Georgia acid soils showed seed treatment was better than foliar spray. No response to molybdenum was observed when more than 0.2 pound per acre was applied. Subsequent research by the same author (15) and others (1, 22) indicated that there is very little difference between seed-treated and foliar sprays.

SUMMARY AND CONCLUSIONS

Foliar sprays can be useful for supplying nutrients to plants in many different situations. Their success will depend on such factors as the weather, type of nutrient compound used, method of application, and concentration of the element. These factors are different for each plant species.

The macronutrients are required in large quantities by plants. Consequently, attempting to supply all the nutrients by foliar sprays is usually impractical. However, in periods of stress, such as cold, drought, disease, pruning, or other injury, foliar sprays of nitrogen, phosphorus, and potassium can be useful for temporary supplemental nutrition.

Calcium, magnesium, and sulfur are also useful for stress periods. Magnesium sprays are especially useful for controlling magnesium deficiencies in such crops as apples, celery, tomatoes, and grapes. Soil treatments are also effective for controlling magnesium deficiencies but usually require

up to 3 years to be effective, whereas foliar sprays are effective immediately. When foliar sprays of macronutrients are used, many plant species suffer leaf burn. For tree crops, leaf burn can be avoided by applying sprays to the dormant tree.

The micronutrients show more promise for foliar sprays. These elements are required in smaller amounts, and less repeated sprayings are necessary to maintain nutrient balance. However, the range between sufficient and toxic is narrow, and care must be exercised.

The micronutrients iron, zinc, copper, and manganese decrease in availability from the soil as the soil pH increases. Consequently, when soil is overlimed, a practical method of overcoming deficiencies is through foliar sprays. This is especially true for iron and zinc. Large quantities of these two elements added to the soil are usually ineffective in correcting deficiencies. Many pesticides contain copper, and deficiencies of this element are not as common as iron or zinc deficiencies. Boron sprays are especially useful during drought, when availability of boron is low. Repeated sprayings are necessary, as boron is only slightly mobile in the plant. Molybdenum is also only slightly mobile; however, the requirement is so small that foliar sprays are usually successful.

Foliar applications of nutrients must be coupled with intensive high-level management. Plant tissue should be analyzed continuously for nutritional status. A need for supplemental foliar sprays should be clearly established before they are used. The soil will remain the principal storehouse for nutrients, with foliar sprays being used for supplemental fertilization.

LITERATURE CITED

(1) Boswell, F. C., and Anderson, O. E.
1969. Effect of time of molybdenum application on soybean yield and on nitrogen, oil, and molybdenum contents. Agron. Jour. 61: 58-60.

(2) Boynton, D.
1954. Nutrition by foliar applications. Amer. Rev. Plant Physiol. 5: 31-54.

(3) Broyer, T. C.
1959. The macronutrient elements. Amer. Rev. Plant Physiol. 10: 277-300.

(4) Bukovac, M. J., and Wittwer, S. H.
1957. Absorption and mobility of foliar applied nutrients. Plant Physiol. 32: 428-435.

(5) Chafe, S. C., and Wardrop, A. B.
1973. Fine structural observations on the epidermis. II. The cuticle. Planta (Berlin) 109: 39-48.

(6) Dolokhov, V. L.
1957. Effect of nutrition by foliar application on the intensity of photosynthesis. Fiziol. Rast. 4: 183-191.

(7) Downing, A.
1869. Fruits and fruit trees of America. 2d ed., 107 pp. New York.

(8) Eddings, J. L., and Brown, A. L.
1967. Absorption and translocation of foliar-applied iron. Plant Physiol. 42: 15-19.

(9) Forsyth, W.
1802. A treatise on the culture and management of fruit trees. 384 pp. Philadelphia.

(10) Franke, W.
1961. Ectodesmata and foliar absorption. Amer. Jour. Bot. 48: 683-691.

(11) ________
1967. Mechanisms of foliar penetration of solutions. Amer. Rev. Plant Physiol. 18: 281-300.

(12) ________
1969. Ectodesmata in relation to binding sites for inorganic ions and urea on isolated cuticular membrane surfaces. Amer. Jour. Bot. 56 (4): 432-435.

(13) Gris, E.
1844. Nouvelles expériences sur l'action des composés rerrugineux solubles appliqués à la végétation et spécialement au treatment de la chlorose et à la debilité des plantes. Compt. Rend. (Paris) 19: 1118-1119.

(14) Hagler, T. B.
1957. Effect of magnesium sprays on muscadine grapes. Amer. Soc. Hort. Sci. Proc. 70: 178-182.

(15) Hagstrom, G. R., and Berger, K. C.
1965. Molybdenum deficiencies of Wisconsin soils. Soil Sci. 100: 50-56.

(16) Jarvis, L. R., and Wardrop, A. B.
1974. The development of the cuticle in Phormium tenax. Planta (Berlin) 119: 101-112.

(17) Johnson, K. E. E., Davis, J. F., and Benne, E. J.
1957. Control of magnesium deficiency in Utah 10B celery grown on organic soil. Soil Sci. Soc. Amer. Proc. 21: 528-532.

(18) Keogh, J. L., and Maples, R.
1969. Boron for cotton and soybeans on loessial plains soils. Ark. Agr. Expt. Sta. Bul. 740, 19 pp.

(19) Levi, E.
1970. Penetration, retention and transport of foliar applied single salts of Na, K, Rb, and Cs. Physiol. Plant. 23: 811-819.

(20) Lindsay, W. L.
1971. Inorganic phase equilibria of micronutrients in soils. Micronutrients in Agr. Symp., Muscle Shoals, Ala., Proc. 1971, pp. 41-57.

(21) McFarlane, J. C., and Berry, W. L.
1974. Cation penetration through isolated leaf cuticles. Plant Physiol. 53: 723-727.

(22) Parker, M. B., and Harris, H. B.
1962. Soybean response to molybdenum and lime and the relationship between yield and chemical composition. Agron. Jour. 54: 480-483.

(23) Stark, F. C., and Matthews, W. A.
1958. Improving quality of cantaloups and tomatoes by foliar feeding. Md. Univ. Agr. Expt. Sta. Bul. 464, 19 pp.

(24) Teubner, F. C., Wittwer, S. H., Long, W. G., and Tukey, H. B.
1957. Some factors affecting absorption and transport of foliar-applied nutrients as revealed by radioactive isotopes. Mich. State Univ. Agr. Expt. Sta. Quart. Bul. 39: 398-415, illus.

(25) Turrell, F. M., and Weber, J. R.
1955. Elemental sulfur dust, a nutrient for lemon leaves. Science 122: 119-120.

(26) Wittwer, S. H., and Bukovac, M. J.
1969. The uptake of nutrients through leaf surfaces. Handb. der Pflanzenernähr. u. Düngung 1, pp. 235-261.

(27) ________ and Teubner, F. G.
1959. Foliar absorption of mineral nutrients. Amer. Rev. Plant Physiol. 10: 13-32.

(28) Yamada, Y., Rasmussen, H. P., Bukovac, M. J., and Wittwer, S. H.
1966. Binding sites for inorganic ions and urea on isolated cuticular membrane surfaces. Amer. Jour. Bot. 53 (2): 170-172.

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